We Claim

1. In a method comprising the steps of (a) transmitting a plurality of waveforms from a transducer at a fundamental frequency, (b) receiving reflected ultrasonic energy at a harmonic of the fundamental frequency and (c) generating an image responsive to the reflected energy at the harmonic in an ultrasound system, an improvement wherein step (a) comprises the step of:

(a1) pre-distorting at least one of said plurality of waveforms as a function of a non-linear characteristic.

2. The method of Claim 1 wherein step (a1) comprises pre-distorting said at least one waveform as a function of a waveform propagation non-linear characteristic.

3. The method of Claim 2 wherein upon propagation in range along an ultrasound line, a spectral peak of a harmonic component at a second region is less than said spectral peak of said harmonic component at a first region by an amount that exceeds that attributable to only attenuation, wherein said second region is greater in range along said ultrasound line than said first region.

4. The method of Claim 2 wherein said at least one waveform comprises a harmonic spectral peak suppressed by about 4 dB or more at a region of interest spaced from said transducer along said ultrasound line as compared to a harmonic spectral peak at said region associated with transmission of a waveform comprising substantially only a fundamental spectral component adjacent said transducer

5. The method of Claim 1 wherein step (a1) comprises pre-distorting said at least one waveform as a function of a non-linear characteristic of a device.

6. The method of Claim 5 wherein step (a1) comprises pre-distorting said at least one waveform as a function of a non-linear characteristic of the transducer.

7. The method of Claim 5 wherein step (a1) comprises pre-distorting said at least one waveform as a function of a non-linear characteristic of a lens.

8. The method of Claim 5 further comprising steps:

(c) transmitting at least one test waveform;

(d) receiving echoes associated with the test waveform; and

(e) determining pre-distortion parameters in response to the echoes.

9. The method of Claim 5 further comprising step (c) of storing pre-distortion parameters associated with the transducer.

10. The method of Claim 1 wherein step (a1) comprises:

(1) pre-distorting a plurality of said waveforms; and

(2) transmitting each of said plurality of said waveforms from a different one of a plurality of transducer elements in a single transmit event.

11. The method of Claim 1 wherein:

step (a1) comprises transmitting first and second ultrasonic pulses, the second ultrasonic pulse associated with a substantially opposite polarity than the first ultrasonic pulse, the first and second ultrasonic pulses pre-distorted as a function of the non-linear characteristic; and

step (b) comprises:

(b1) receiving first and second ultrasonic receive pulses, each receive pulse associated with a respective one of the transmit pulses, and each receive pulse comprising a respective fundamental receive component and a respective harmonic receive component; and

(b2) combining at least two of the receive pulses to form a composite harmonic signal.

12. The method of Claim 1 wherein:

step (a1) comprises transmitting a set of ultrasonic transmit pulses into a region, each transmit pulse comprising respective first and second transmit components, the first transmit components associated with selected ones of the transmit pulses modulated at a fundamental ultrasonic frequency and being out of phase by a phase difference, the second transmit components associated with said selected ones of the transmit pulses being substantially in phase, at least one of said components pre-distorted as a function of the non-linear characteristic; and

step (b) comprises:

(b1) receiving a plurality of ultrasonic receive pulses from the region, each receive pulse associated with a respective one of the transmit pulses, and each receive pulse comprising a respective fundamental receive component and a respective harmonic receive component; and

(b2) combining at least two of the receive pulses to form a composite signal, said phase difference effective to cause the fundamental receive components to destructively interfere to a different extent than the harmonic receive components in the summing step.

13. The method of Claim 12 wherein step (a1) comprises transmitting a set of unipolar ultrasonic transmit pulses

14. The method of Claim 1 wherein step (a1) comprises:

(1) generating a set of fundamental waveforms associated with a first apodization, first delays and first pulse shapes;

(2) generating a set of second harmonic waveforms associated with the first delays, a second pulse shape proportional to the first pulse shape, and a second apodization proportional to the first apodization; and

(3) combining the set of fundamental waveforms and the second of second harmonic waveforms.

15. The method of Claim 1 wherein step (a1) comprises generating a set of pre-distorted waveforms, each of said pre-distorted waveforms comprising a fundamental and a harmonic component, said set of pre-distorted waveforms associated with a different apodization for said fundamental component than for said harmonic component.

16. The method of Claim 1 wherein step (a1) comprises adding a second harmonic component.

17. The method of Claim 1 wherein step (a1) comprises transmitting a waveform comprising a pulse spatially defined by a first zero value adjacent to a first non-zero value of said pulse and a successive second zero value adjacent to a second non-zero value of said pulse, wherein a peak amplitude of said pulse is a first distance from said first zero value, said first distance displaced from half a distance between said first and second zero values by at least 1% of said distance between said first and second zero values.

18. In a method comprising the steps of (a) transmitting a plurality of waveforms from a transducer at a fundamental frequency and (b) receiving reflected ultrasonic energy at a harmonic of the fundamental frequency in an ultrasound system, an improvement wherein step (a) comprises the step of:

(a1) transmitting a waveform comprising a fundamental spectral component and a harmonic spectral component from a transducer, such that upon propagation in range along an ultrasound line, a spectral peak of said harmonic component at a second region is less than said spectral peak of said harmonic component at a first region by an amount that exceeds that attributable to only attenuation, wherein said second region is greater in range along said ultrasound line than said first region.

19. The method of Claim 18 wherein the step (a1) comprises attributing an amount of decrease in said peak to attenuation as a function of about 0.5 dB/cm/MHz.

20. The method of Claim 18 wherein the step (a1) comprises transmitting said waveform, wherein in said peak is a first value down from a peak of said fundamental spectral component at said first region and a second value down at said second region, an absolute value of said second value greater than an absolute value of said first value by an amount that exceeds that attributable to attenuation.

21. The method of Claim 18 wherein the step (a1) comprises transmitting said waveform responsive to a sampling rate, wherein said sampling rate is 8 or greater samples per cycle of a carrier signal.

22. The method of Claim 20 wherein the step (a1) comprises transmitting a pre-distorted waveform comprising said peak of said harmonic spectral component suppressed by about 4 dB or more at said second region as compared to a harmonic spectral peak at said second region associated with transmission of a waveform comprising substantially only a fundamental spectral component at said first region, said first region adjacent to said transducer.

23. The method of Claim 18 wherein the step (a1) comprises transmitting said waveform comprising a positive pulse temporally defined by first and second successive zero crossings and a negative pulse temporally defined by third and fourth successive zero crossings, wherein a peak amplitude of said positive pulse is a first time from said first zero crossing that is greater than half a second time between said first and second zero crossings and a peak amplitude of said negative pulse is a third time from said third zero crossing that is less than half a fourth time between said third and fourth zero crossings.

24. The method of Claim 23 wherein the step (a1) comprises transmitting said waveform wherein said second and fourth times are equal.

25. The method of Claim 20 wherein the step (a1) comprises transmitting said waveform wherein said second region corresponds to a focal region.

26. The method of Claim 25 wherein the step (a1) comprises transmitting said waveform wherein said focal region corresponds to a mechanical focal region.

27. The method of Claim 25 wherein the step (a1) comprises transmitting said waveform wherein said focal region corresponds to a focal region responsive to a delay.

28. The method of Claim 18 wherein the step (a1) comprises transmitting said waveform wherein said peak is an equal value at a third region and said first region, wherein said third region is more distant in range from said transducer than said first and second regions.

29. The method of Claim 18 wherein the step (a1) comprises the step (a2) of transmitting a plurality of said waveforms.

30. The method of Claim 29 wherein the step (a2) comprises setting a characteristic selected from the group of: delay profile, apodization, aperture width and combinations thereof of a harmonic beam different from a fundamental beam.

31. The method of Claim 25 wherein the step (a1) comprises transmitting said waveform wherein said absolute value of said second value is at least 4 dB greater than absolute value of said first value in addition to said amount attributable to attenuation.

32. The method of Claim 18 wherein the step (a1) comprises transmitting said waveform comprising said peak corresponding to a second harmonic band.

33. The method of Claim 28 wherein the step (a1) comprises transmitting said waveform wherein said peak is at a lowest level along said ultrasound line at said second region.

34. The method of Claim 33 wherein the lowest level is approximately zero.

35. The method of Claim 34 wherein a level of said peak corresponding to a position, z, of said waveform adjacent said second region, z=0, is given as $P(z)=1/2\beta\varepsilon^2\omega_0\rho_0 c_0 z$, wherein β is a coefficient of non-linearity, ε is the acoustic Mach number, ω_0 is 2π(center frequency), ρ_0 is the density and c_0 is the speed of sound.

36. In a method comprising the steps of (a) transmitting a plurality of waveforms from a transducer at a fundamental frequency and (b) receiving reflected ultrasonic energy at a harmonic of the fundamental frequency in a ultrasound system, an improvement wherein step (a) comprises the step of:

(a1) transmitting a pre-distorted waveform along an ultrasound line, said pre-distorted waveform comprising a harmonic spectral peak suppressed by about 4 dB or more at a region of interest spaced from said transducer along said ultrasound line as compared to a harmonic spectral peak at said region associated with transmission of a waveform comprising substantially only a fundamental spectral component adjacent said transducer.

37. The method of Claim 36 wherein the step (a1) comprises transmitting a waveform wherein said peak is 40 dB or more down from a fundamental spectral peak at said region of interest.

38. The method of Claim 36 wherein the step (a1) comprises transmitting said waveform comprising a positive pulse temporally defined by first and second successive zero crossings and a negative pulse temporally defined by said second zero crossing and a successive third zero crossing, wherein a peak amplitude of said positive pulse is a first time from said first zero crossing that is more than half a second time between said first and second zero crossings and a peak amplitude of said negative pulse is a third time from said second zero crossing that is less than half a fourth time between said second and third zero crossings.

39. The method of Claim 38 wherein the step (a1) comprises transmitting said waveform wherein said second and fourth times are equal.

40. In a method comprising the steps of (a) transmitting a plurality of waveforms from a transducer at a fundamental frequency and (b) receiving reflected ultrasonic energy at a harmonic of the fundamental frequency in an ultrasound system, an improvement wherein step (a) comprises the step of:

(a1) transmitting a waveform comprising a pulse spatially defined by a first zero value adjacent to a first non-zero value of said pulse and a successive second zero value adjacent to a second non-zero value of said pulse, wherein a peak amplitude of said pulse is a first distance from said first zero value, said first distance displaced from half a distance between said first and second zero values by at least 1% of said distance between said first and second zero values.

41. The method of Claim 40 wherein the step (a1) comprises transmitting said waveform wherein said first distance is a function of the polarity of said pulse.

42. The method of Claim 40 wherein the step (a1) comprises transmitting said waveform comprising a positive pulse defined by said first zero value associated with an first position prior to said second zero value, said first and second zero values being successive zero crossings.

43. The method of Claim 40 wherein the step (a1) comprises transmitting said pulse comprising a negative pulse, wherein said first distance is more than half said distance between said first and second zero values, said first and second zero values being successive zero crossings.

44. The method of Claim 40 wherein the step (a1) comprises transmitting said pulse comprising a positive pulse, wherein said first distance is less than half said distance between said first and second zero values.

45. The method of Claim 44 wherein the step (a1) further comprises transmitting said waveform comprising a negative pulse defined by said second zero value and a third zero value, wherein a negative peak amplitude of said negative pulse is a third distance from said second zero value that is more than half a fourth distance between said second and third zero values.

46. The method of Claim 45 wherein the step (a1) comprises transmitting said waveform wherein said second and fourth distances are equal.

47. The method of Claim 40 wherein the step (a1) comprises transmitting said waveform wherein said first distance is a function of a distance of a region of interest from said transducer.

48. The method of Claim 47 wherein the step (a1) comprises transmitting said waveform wherein said first distance corresponds to a delay in time.

49. The method of Claim 47 wherein the step (a1) comprises transmitting said waveform wherein said first distance corresponds to $\beta\varepsilon\lambda$ for every wavelength, λ, from said transducer to said region of interest, wherein β is a coefficient of non-linearity, and ε is the acoustic Mach number.

50. The method of Claim 45 wherein the step (a1) comprises transmitting said waveform wherein said third distance is a function of distance of a region of interest from said transducer.

51. The method of Claim 47 wherein the step (a1) comprises transmitting said waveform wherein said third distance corresponds to an advance in time.

52. The method of Claim 50 wherein the step (a1) comprises transmitting said waveform wherein said third distance corresponds to $\beta\varepsilon\lambda$ for every wavelength, λ, from said transducer to said region of interest, wherein β is a coefficient of non-linearity, and ε is the acoustic Mach number.

53. The method of Claim 45 wherein the step (a1) further comprises transmitting a plurality of wavelengths of said waveform wherein said positive pulse and said negative pulse comprise one wavelength.

54. The method of Claim 53 wherein the step (a1) comprises applying a Gaussian envelope to said waveform.

55. The method of Claim 53 wherein the step (a1) further comprises focusing, apodizing, and transmitting a plurality of said waveforms from a plurality of transducer elements.

56. The method of Claim 55 wherein the step (a1) further comprises focusing said plurality of said waveforms at a first region along a line and transmitting said waveforms a first time.

57. The method of Claim 56 a further comprising the steps of focusing said plurality of said waveforms at a second region along said line and transmitting said waveforms at least a second time.

58. The method of Claim 55 further comprising generating at least one copy of a first waveform, at least said copy and said first waveform comprising said plurality of said waveforms.

59. The method of Claim 40 wherein the step (a1) comprises (a2) summing a first and a second waveform.

60. The method of Claim 59 wherein the step (a2) comprises summing said first waveform corresponding to a fundamental spectrum with said second waveform corresponding to a harmonic spectrum.

61. The method of Claim 59 wherein the step (a2) comprises summing said first waveform corresponding to a first center frequency with said second waveform corresponding to a second center frequency.

62. The method of Claim 61 wherein the step (a2) comprises summing said first waveform with said second waveform, wherein said second frequency is about twice said first frequency.

63. The method of Claim 59 wherein the step (a2) comprises summing said first waveform corresponding to a first envelope with said second waveform corresponding to a second envelope that is about the square of the first envelope in amplitude.

64. The method of Claim 59 further comprising the step (a3) of adjusting the second envelope in amplitude relative to said first envelope.

65. The method of Claim 59 wherein the step (a2) further comprises setting a phase associated with said first waveform substantially the same as a phase associated with said second waveform.

66. The method of Claim 65 further comprising the step (a3) of adjusting the phase associated with said first waveform relative to the phase associated with said second waveform.

67. The method of Claim 40 further comprising the step of (a2) varying a characteristic of said waveform.

68. The method of Claim 67 wherein the step (a2) comprises varying said characteristic selected from the group of: phase, amplitude, bandwidth, center frequency and combinations thereof.

69. The method of Claim 67 further comprising the steps of:

(a3) detecting a first and second value of a parameter responsive to the steps (a1) and (a2), respectively; and

(a4) comparing said first and second values.

70. The method of Claim 69 further comprising the steps of:

providing at least one contrast agent; and

transmitting the waveform corresponding with a lesser value of said parameter at least a second time.

71. The method of Claim 67 wherein the step (a2) comprises varying said characteristic in response to user input information.

72. The method of Claim 40 wherein the step (a1) comprises (a2) displacing said first distance by more than 2 percent of a distance corresponding to a cycle of the fundamental component.

73. The method of Claim 72 wherein the step (a2) comprises displacing said first distance by about 5-20 percent.

74. In a method comprising the steps of (a) transmitting a plurality of waveforms from a transducer at a fundamental frequency and (b) receiving reflected ultrasonic energy at a

harmonic of the fundamental frequency in an ultrasound system, an improvement wherein step (a) comprises the step of:

(a1) transmitting a waveform comprising fundamental and harmonic spectral components corresponding to fundamental and harmonic temporal signal components, respectively, from a transducer, wherein a first negative sloped zero crossing associated with said harmonic signal component is less than a quarter period from a second negative sloped zero crossing associated with the fundamental signal component, said period and quarter period associated with said fundamental signal component.

75. The method of Claim 74 wherein the step (a1) comprises transmitting said waveform wherein said first zero crossing is less than said quarter period after said second zero crossing.

76. The method of Claim 74 wherein the step (a1) comprises transmitting said waveform wherein said first zero crossing is less than said quarter period before said second zero crossing.

77. The method of claim 74 wherein the step (a1) comprises transmitting said waveform wherein a peak of said harmonic component is at most 40 dB down from a peak of said fundamental component.

78. In a method comprising the steps of (a) transmitting a plurality of waveforms from a transducer at a fundamental frequency and (b) receiving reflected ultrasonic energy at a harmonic of the fundamental frequency in an ultrasound system, an improvement wherein step (a) comprises the step of:

(a1) transmitting a waveform comprising at least one positive pulse temporally beginning and ending at first and second successive zero values and at least one negative pulse temporally beginning and ending at third and fourth successive zero values, wherein a center of an amplitude distribution of said positive pulse is at a first time that is at least one percent greater than half a time between said first and zero values and a center of an

amplitude distribution of said negative pulse is at a second time that is at least one percent less than half a time between said third and fourth zero values.

79. In a method comprising the steps of (a) transmitting a plurality of waveforms from a transducer at a fundamental frequency and (b) receiving reflected ultrasonic energy at a harmonic of the fundamental frequency in an ultrasound system, an improvement wherein step (a) comprises the step of:

(a1) transmitting a waveform sampled at least 8 times a cycle from a transducer, said waveform comprising a fundamental spectral component and a harmonic spectral component, such that upon propagation, a peak of said harmonic spectral component is reduced at a second region as compared to said peak at a first region, said second region greater in range along an ultrasound line than said first region, said reduction due at least to nonlinear propagation.

80. The method of Claim 79 wherein the step (a1) comprises transmitting said waveform wherein said reduction is due to at least nonlinear propagation and dissipation.

81. In a method comprising the steps of (a) transmitting a plurality of waveforms from a transducer at a fundamental frequency and (b) receiving reflected ultrasonic energy at a harmonic of the fundamental frequency in a ultrasound system, an improvement wherein step (a) comprises the step of:

(a1) transmitting a pre-distorted waveform sampled at least 8 times a cycle, said waveform comprising a fundamental spectral component and a harmonic spectral component, wherein a peak of said harmonic spectral component is at most about 40 dB down from a peak of said fundamental spectral component at the transducer.

82. The method of Claim 81 wherein the step (a1) comprises the step (a2) of transmitting said waveform comprising a pulse spatially defined by a first zero value adjacent a first non-zero value of said pulse and a second zero value adjacent a second non-zero value of said pulse, wherein a peak amplitude of said pulse is a first distance

from said first zero value, said first distance displaced from half a distance between said first and second zero values.

83. The method of Claim 82 wherein the step (a2) comprises (a3) displacing said first distance by more than 2 percent of a distance corresponding to a cycle of the fundamental component.

84. The method of Claim 83 wherein the step (a3) comprises displacing said first distance by about 5-20 percent.

85. In a method comprising the steps of (a) transmitting a plurality of waveforms from a transducer at a fundamental frequency and (b) receiving reflected ultrasonic energy at a harmonic of the fundamental frequency in a ultrasound system, an improvement wherein step (a) comprises the step of:

(a1) transmitting at least first and second waveforms corresponding to first and second channels, each of said first and second waveforms comprising a fundamental spectral component and a harmonic spectral component, wherein a characteristic of said harmonic spectral component as compared to said fundamental component is different for said first channel than said second channel.

86. The method of Claim 85 wherein the step (a1) comprises the step of setting said characteristic selected from the group of: delays, phases, center frequencies, bandwidths, amplitudes and combinations thereof.

87. The method of Claim 85 wherein the characteristic referred to in step (a1) is the relative amplitude of the harmonic component as compared to the fundamental component.

88. The method of Claim 85 wherein the characteristic referred to in step (a1) is the relative phase of the harmonic component as compared to the fundamental component.

89. The method of Claim 85 wherein the characteristic referred to in step (a1) is the relative delay of the harmonic component as compared to the fundamental component.

90. The method of Claim 85 wherein the characteristic referred to in step (a1) is the relative center frequency of the harmonic component as compared to the fundamental component.

91. The method of Claim 85 wherein the characteristic referred to in step (a1) is the relative bandwidth of the harmonic component as compared to the fundamental component.

92. The method of Claim 85 wherein the step (a1) comprises transmitting a plurality of waveforms corresponding to a plurality of channels, wherein an apodization associated with a harmonic beam is different than an apodization associated with a fundamental beam.

93. The method of Claim 85 wherein the step (a1) comprises transmitting a plurality of waveforms corresponding to a plurality of channels, wherein a delay profile associated with a harmonic beam is different than a delay profile associated with a fundamental beam.

94. The method of Claim 85 wherein the step (a1) comprises transmitting a plurality of waveforms corresponding to a plurality of channels, wherein an aperture width associated with a harmonic beam is different than an aperture width associated with a fundamental beam.